International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878, Impact Factor (2014): 3.05

Power Flow Improvement in Transmission Line with reduced DC Link Capacitor Using UPFC

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Abstract: ***This paper proposes a new real and reactive power coordination controller for a unified power flow controller (UPFC). The basic control for the UPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the UPFC. To avoid instability/loss of DC link capacitor voltage during transient conditions, a new real power coordination controller has been designed. The need for reactive power coordination controller for UPFC arises from the fact that excessive bus voltage (the bus to which the shunt converter is connected) excursions occur during reactive power transfers. A new reactive power coordination controller has been designed to limit excessive voltage excursions during reactive power transfers. MATLAB/SIMULINK simulation results have been presented to show the improvement in the performance of the UPFC control with the proposed real power and reactive power coordination controller.***

1. Introduction

UPFC is the most comprehensive multivariable flexible ac transmission system (FACTS) controller. Simultaneous control of multiple power system variables with UPFC posses enormous difficulties. In addition, the complexity of the UPFC control increases due to the fact that the controlled and the control variables interact with each other UPFC which consists of a series and a shunt converter connected by a common dc link capacitor can simultaneously perform the function of transmission line real/reactive power flow control in addition to UPFC bus voltage/shunt reactive power control [1]. The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The interaction between the series injected voltage and the transmission line current leads to real and reactive power exchange between the series converter and the power system. Under steady state conditions, the real power demand of the series converter is supplied by the shunt converter. But during transient conditions, the series converter real power demand is supplied by the dc link capacitor. If the information regarding the series converter real demand is not conveyed to the shunt converter control system, it could lead to collapse of the dc link capacitor voltage and subsequent removal of UPFC from operation

In contrast to real power coordination between the series and shunt converter control system, the control of transmission line reactive power flow leads to excessive voltage excursions of the UPFC bus voltage during reactive power transfers. This is due to the fact that any change in transmission line reactive power flow achieved by adjusting the magnitude/phase angle of the series injected voltage of the UPFC is actually supplied by the shunt converter. The excessive voltage excursions of the UPFC bus voltage is due to absence of reactive power coordination be-tween the series and the shunt converter control system. This aspect of UPFC control has also not been investigated [2]–[15]. A new reactive power coordination controller between the series and the shunt converter control system has been designed to reduce UPFC bus voltage excursions during reactive power transfers.

UPFC control system that includes the real and reactive power coordination controller has been designed and its performance evaluated. Sections II and III describes the basic control strategy and control system for a UPFC. Section IV provides the details of the real and reactive power coordination controller.

2. Control Strategy for UPFC

A. Shunt Converter Control Strategy

The shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. In this case, the shunt converter voltage is decomposed into two components. One component is in-phase and the other in quadrature with the UPFC bus voltage. De-coupled control system has been employed to achieve simultaneous control of the UPFC bus voltage and the dc link capacitor voltage.

B. Series Converter Control Strategy

The series converter of the UPFC provides simultaneous control of real and reactive power flow in the transmission line. To do so, the series converter injected voltage is decomposed into two components. One component of the series injected voltage is in quadrature and the other in-phase with the UPFC bus voltage. The quadrature injected component controls the transmission line real power flow. This strategy is similar to that of a phase shifter. The in-phase component controls the transmission line reactive power flow. This strategy is similar to that of a tap changer.

C. Shunt Converter Control System

Fig. 1 shows the de-coupled control system for the shunt converter. The D-axis control system controls the dc link capacitor voltage (V_{dc}) and the Q-axis control system controls the UPFC bus voltage (V_{ufcbus}) /shunt reactive power. The details of the de-coupled control system design can be found in [16], [17]. The de-coupled control system has been de-signed based on linear control system techniques and it consists of an outer loop control system that sets the reference for the inner control system loop. The inner control system loop tracks the reference.

D. Series Converter Control Parameters

1) Transmission line real power flow controller parameters

$$K_p=1\ ; \quad K_i=4;$$

E. Series Converter Control System

Fig. 2 shows the overall series converter control system. The transmission line real power flow (P_{line}) is controlled by in-jecting a component of the series voltage in quadrature with the UPFC bus voltage $(V_{se}Q)$. The transmission line reactive power (Q_{line}) is controlled by modulating the transmission line side bus voltage reference $(V_{lineref})$. The transmission line side bus voltage is controlled by injecting a component of the series voltage in-phase with the UPFC bus voltage $(V_{se}D)$. The pa-rameters of the PI controllers

Transmission line reactive power flow controller parameters:

a) Outer loop controller K_p= -0.1; K_i= -1;
b) Inner loop controller K_p= 0.15; K_i= 25;

F. Real Power Coordination Controller

To understand the design of a real power coordination con-troller for a UPFC, consider a UPFC connected to a transmission line as shown in Fig. 3. The interaction between the series in-jected voltage (V_{se}) and the transmission line current (I_{se}) leads to exchange of real power (P_{se}) between the series converter and the transmission line. The real power demand of the series converter (P_{se}) causes the dc link capacitor voltage (V_{dc}) to ei-ther increase or decrease depending on the direction of the real power flow from the series converter. This decrease/increase in dc link capacitor voltage (V_{dc}) is sensed by the shunt converter controller that controls the dc link capacitor voltage (V_{dc}) and acts to increase/decrease the shunt converter real power flow to bring the dc link capacitor voltage (V_{dc}) back to its scheduled value. Alternatively, the real power demand of the series con-verter is recognized by the shunt converter controller only by the decrease/increase of the dc link capacitor voltage (V_{dc}). Thus, the shunt and the series converter operation are in a way sep-arated from each other. To provide for proper coordination be-tween the shunt and the series converter control system, a feed-back from the series converter is provided to the shunt converter control system. The feedback signal used is the real power de-mand of the series converter (P_{se}). The real power demand of the series converter (P_{se}) is converted into an equivalent D-axis current for the shunt converter (i_{Dse}). By doing so, the shunt converter responds immediately to a change in its D-axis current and supplies the necessary series converter real power demand. The equivalent D-axis current (i_{Dsc}) is an additional input to the D-axis shunt converter control system as shown in Fig. 4. Equation (1) shows the relationship between the series converter real power demand (P_{se}) and the shunt converter D-axis current to exchange of real power (P_{se}) between the series converter and the transmission line.

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G. Effect of Real Power Coordination Controller

To study the efficacy of the real power coordination con-troller, a power system shown in Fig. 10 has been considered. The machines are equipped with static exciters and PSS. The generator, exciter, PSS, synchronous motor load, and UPFC pa-rameters are given in Appendix B [21]. The total load in the power system is 700 MW. The load has been modeled as a syn-chronous motor. Generator G2 supplies 500 MW of power and the rest of the power is generated by G1. Generator G1 also sup-plies the system losses. The steady-state power flow in the 345 kV transmission line is 400 MW. The 230 kV transmission line carries 100 MW of power. The UPFC is located at the center of a 160-km 345-kV line.

The shunt converter of the UPFC controls the dc link capacitor voltage (V_{dc}) and the shunt converter reactive power. The series converter of the UPFC controls the real power flow in the transmission line (P_{line}) at 400 MW and the reactive power flow at 100 MVAR. A three-phase fault is conducted at 12 s for 50 ms at bus-B with no change in network configuration. Plot-1 and Plot-2 (enlarged version of Plot-1) of Fig. 11 shows the dc link capacitor voltage with and without the real power coordination controller. The three-phase fault causes the real power to be generated by the UPFC leading to reduction in dc link ca-pacitor voltage. The dc link capacitor voltage drops to about 20 kV. Following the fault removal, the dc link capacitor is charged up by the shunt converter. It is evident from plot-1 and plot-2 of Fig. 11 that the real power coordination controller has signif-icantly improved the recovery of the dc link capacitor voltage under transient conditions. Further, the dc link capacitor voltage oscillations are well damped with real power coordination controller.

3. Modeling of UPFC

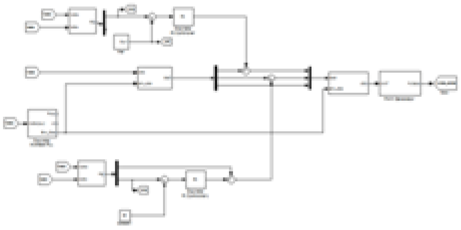

Figure 1: Series controller with coordination

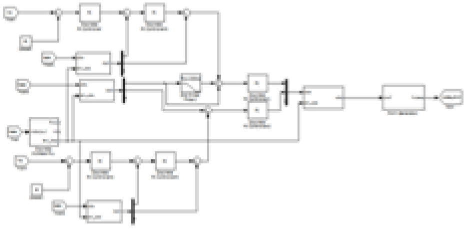

Figure 2: Shunt controller with coordination

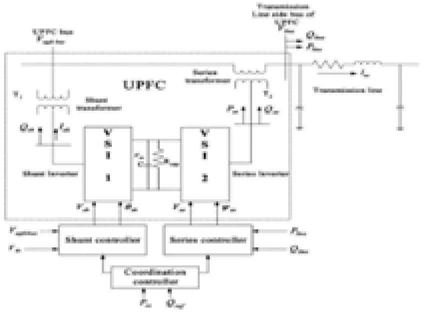

Figure 3: Proposed UPFC configuration

4. Simulation Results

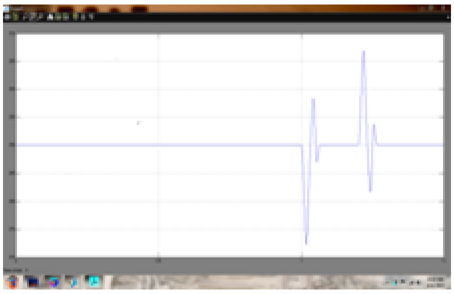

Figure: Active Power of Transmission line

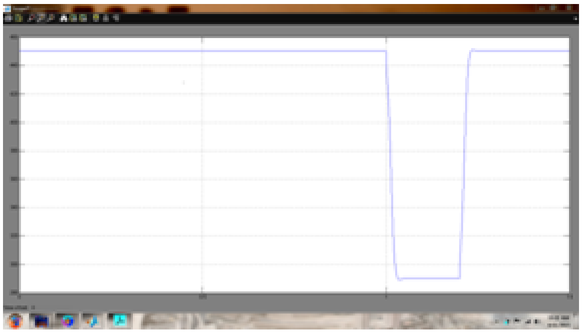

Figure: Reference Active power of system

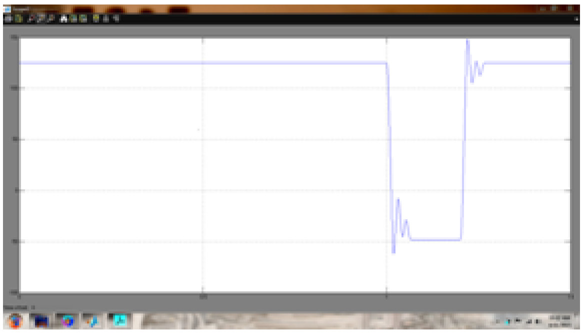

Figure: Reactive power of Transmission line

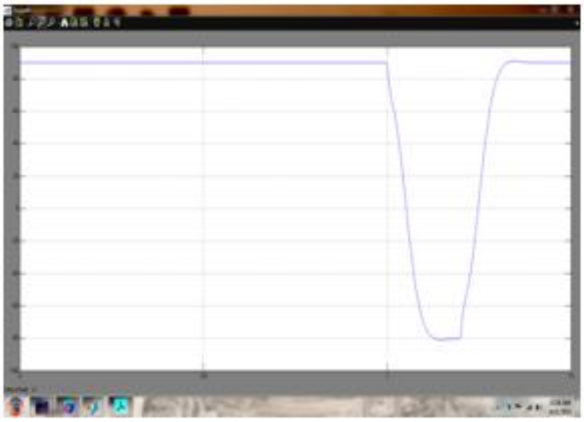

Figure: Reactive power of shunt branch

Figure: UPFC bus Voltagevariaction

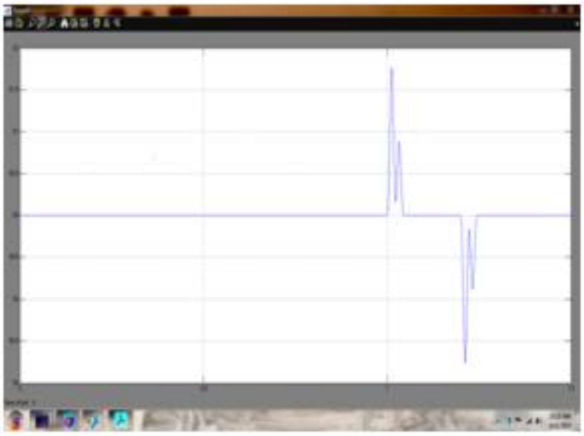

Figure: DC bus Voltage performance

5. Conclusion

This paper has presented a new real and reactive power co-ordination controller for a UPFC. The basic control strategy is such that the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the dc link capacitor voltage. The series converter controls the transmission line real and re-active power flow. The contributions of this work can be sum-marized as follows.

Two important coordination problems have been addressed in this paper related to UPFC control. One, the problem of real power coordination between the series and the shunt converter control system. Second, the problem of excessive UPFC bus voltage excursions during reactive power transfers requiring re-active power coordination.

Inclusion of the real power coordination controller in the UPFC control system avoids excessive dc link capacitor voltage excursions and improves its revovery during transient conditions. PSCAD-EMTDC simulations have been conducted to verify the improvement in dc link voltage excursions during transient conditions Inclusion of reactive power coordination controller helps in significantly reducing UPFC bus voltage excursions during re-active power transfers. The effect on transmission line reactive power flow is minimal.

MATLAB simulations have shown the improvement in power oscillation damping with UPFC.

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